

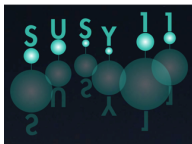
Constructive Interference in the $B \rightarrow \tau\nu$ Amplitude in the MSSM with negative μ

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Outline

- Motivation: $B \rightarrow \tau \nu$ in SM vs. Experiment
- $B \rightarrow \tau \nu$ in the MSSM
 - What large and negative μ can do for us
- Constraints/Consequences for other processes
- Vacuum stability
- Summary

SM vs Experiment

- SM has been verified experimentally to an astounding precision
- However, there are some small(?) deviations
 - $t\bar{t}$ asymmetry
 - ...
 - $\mathcal{BR}(B \rightarrow \tau\nu)$

SM (UTfit)

$$(0.81 \pm 0.12) \times 10^{-4}$$

Experiment

$$(1.68 \pm 0.31) \times 10^{-4}$$

\Rightarrow This is $(2 - 3)\sigma$ discrepancy

- Is this new physics? If so, what could cause this?

$B \rightarrow \tau \nu$: New physics?

- How well is SM value known?

$$\mathcal{BR}(B \rightarrow \tau \nu)_{SM} = \frac{G_F^2 |V_{ub}|^2}{8\pi} m_\tau^2 f_B^2 m_B \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2$$

\Rightarrow Largest error from f_B and V_{ub} :

$$\mathcal{BR}(B \rightarrow \tau \nu)_{SM} \sim (0.73 - 0.83) \times 10^{-4}$$

- Still no agreement with experiment ($\sim 1.6 \times 10^{-4}$).

Working assumption

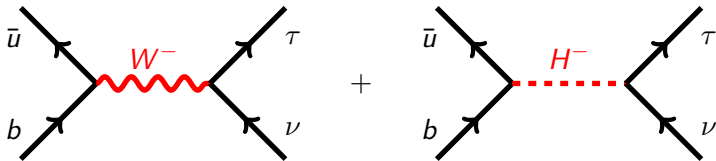
Assume this is due to new physics.

$B \rightarrow \tau \nu$ in general Two Higgs Doublet models

- The charged Higgs H^\pm can mediate (almost) the same interactions like the W^\pm

$$\mathcal{L} \sim \bar{\Psi}_L \gamma^\mu W_\mu \Psi_L + \bar{\Psi}_L \cdot \phi_H \psi_R$$

- Leptonic B decays get another contribution (compared to SM)

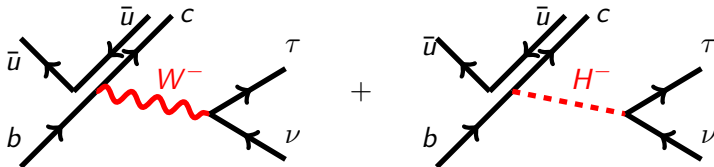


$$\frac{\mathcal{BR}(B \rightarrow \tau \nu)_{2HDM}}{\mathcal{BR}(B \rightarrow \tau \nu)_{SM}} = \left| 1 + \frac{m_B^2}{m_b m_\tau} C_{NP}^\tau \right|^2$$

\Rightarrow Looks promising.

$B \rightarrow D\tau\nu$ in the MSSM

- A closely related decay is $B \rightarrow D\tau\nu$



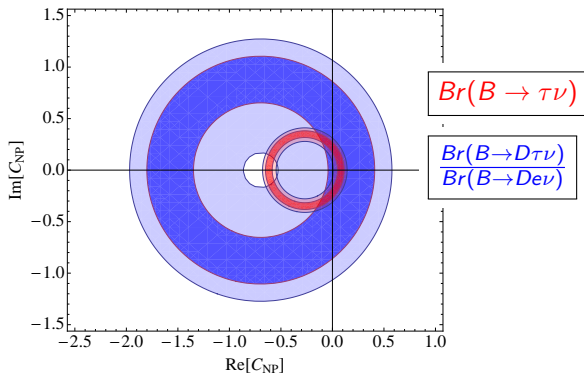
- For better systematics normalize to $\mathcal{BR}(B \rightarrow D\tau\nu)$:

$$\frac{\mathcal{BR}(B \rightarrow D\tau\nu)}{\mathcal{BR}(B \rightarrow D\tau\nu)} = (0.28 \pm 0.02) \times [1 + 1.38(3)\text{Re}C_{NP}^\tau + 0.88(2)|C_{NP}^\tau|^2]$$

\Rightarrow How does this compare to $\mathcal{BR}(B \rightarrow \tau\nu)$

Fit for C_{NP}

- Allowed region with 1σ and 2σ contours in the complex C_{NP} plane:

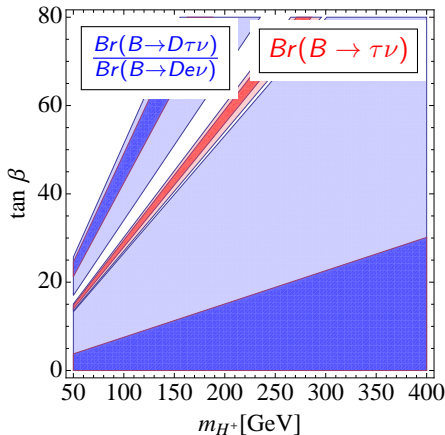


\Rightarrow Best fit for real $C_{NP} \sim +0.1$.

From now on. assume that C_{NP} is real.

C_{NP} in the MSSM

- In a specific model we can compute C_{NP}



In the MSSM

$$C_{NP}^{\tau} = -\frac{m_b m_{\tau}}{m_{H^+}^2} \tan^2 \beta$$

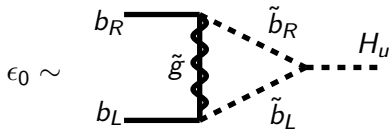
- This is negative!
- \Rightarrow No overlap in preferred regions.
- Can we change the sign?

C_{NP} in the MSSM

- C_{NP} gets loop correction from the bottom mass m_b

$$C_{NP}^T = -\frac{m_b m_\tau}{m_{H^+}^2} \frac{\tan^2 \beta}{1 + \epsilon_0 \tan \beta}$$

- The loop correction is



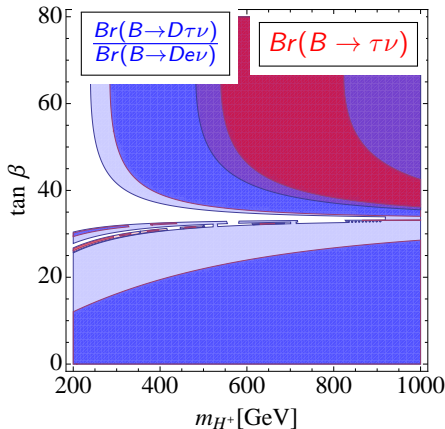
Measure of $U(1)_{PQ}$ violation in the MSSM

$$\epsilon_0 = \frac{2\alpha_s}{3\pi} M_3 \mu I(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2, M_3^2)$$

$\Rightarrow C_{NP}$ is positive, if μ is negative and $\tan \beta$ large: $1 + \epsilon_0 \tan \beta < 0$.

Fit for C_{NP}

- “Usually” $|\epsilon_0| \lesssim 1 - 2\%$, but assume we had $\epsilon_0 = -3\%$:



In MSSM

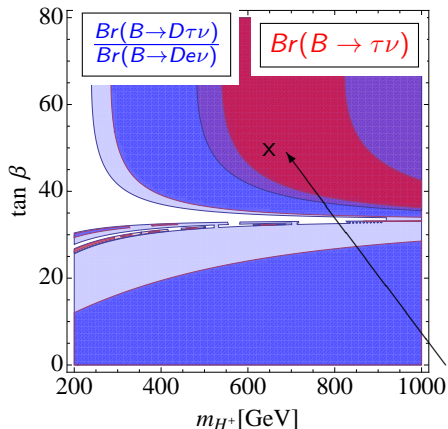
$$C_{NP}^{\tau} = -\frac{m_b m_{\tau}}{m_{H^+}^2} \frac{\tan^2 \beta}{1 + \epsilon_0 \tan \beta}$$

\Rightarrow Large $\tan \beta$ and m_{H^+}

- Can be $|\epsilon_0|$ this big?
- How will this manifest in other measurements?

Fit for C_{NP}

- “Usually” $|\epsilon_0| \lesssim 1 - 2\%$, but assume we had $\epsilon_0 = -3\%$:



In MSSM

$$C_{NP}^T = -\frac{m_b m_\tau}{m_{H^+}^2} \frac{\tan^2 \beta}{1 + \epsilon_0 \tan \beta}$$

⇒ Large $\tan \beta$ and m_{H^+}

- Can be $|\epsilon_0|$ this big?
- How will this manifest in other measurements?

Reference point: $\epsilon_0 = -3\%$

$$\tan \beta = 50, m_{H^+} = 650 \text{ GeV}$$

Other observables

- Other observables strongly affected by large, negative μ
 - Penguin decay $b \rightarrow s\gamma$
 - Anomalous magnetic moment of the muon $a_\mu = \frac{g_\mu - 2}{2}$
 - Rare decay $B_s \rightarrow \mu\mu$
- Mass constraints from direct searches.

Penguin decay $b \rightarrow s\gamma$

Experimental value

$$\mathcal{BR}(b \rightarrow s\gamma)_{\text{exp}} = (355 \pm 24) \times 10^{-6}$$

- Receives contributions from charginos and charged Higgses

$$\mathcal{BR}(b \rightarrow s\gamma)|_{\chi^\pm} \propto \mu A_t \frac{\tan \beta}{1 + \epsilon \tan \beta} (\dots)$$

$$\mathcal{BR}(b \rightarrow s\gamma)|_{H^\pm} \propto h_t \frac{m_b}{v(1 + \epsilon \tan \beta)} (\dots) - \mu M_3 \frac{m_b \tan \beta}{v(1 + \epsilon \tan \beta)} (\dots)$$

\Rightarrow Need $A_t > 0$ to cancel competing contributions.

Anomalous magnetic moment $a_\mu = \frac{g_\mu - 2}{2}$

Experimental value of

$$\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (23.9 \pm 9.9) \times 10^{-10}$$

⇒ Discrepancy between the SM and the experimental value of the myon gyromagnetic moment

- How do SUSY partners contribute?

→ For large $\tan \beta$ and μ

$$\Delta a_\mu^{\text{SUSY}} \propto \frac{m_\mu^2}{M_{\text{SUSY}}^2} \tan \beta \text{ sign}(\mu M_{1,2})$$

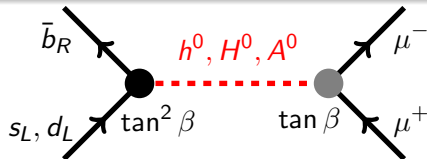
⇒ Need $M_{1,2} < 0$ to get the needed positive contribution.

[Anomaly mediation: $M_i \propto \alpha_i b_i$, with $b_i = (3, -1, -33/5)$]

Rare decay $B_s \rightarrow \mu\mu$

Experimental value

$$\mathcal{BR}(B_s \rightarrow \mu^+ \mu^-)_{\text{exp}} \leq 1.1 \times 10^{-8}$$



- Strongly enhanced for large $\tan \beta$:

$$\sim 13.2 \times 10^{-8} \frac{(16\pi^2 \epsilon_Y)^2}{(1 + \epsilon_3 \tan \beta)^2 (1 + \epsilon_0 \tan \beta)^2} \left[\frac{\tan \beta}{50} \right]^6 \left[\frac{645 \text{ GeV}}{M_A} \right]^4,$$

Weak contribution: $\epsilon_Y \sim \frac{1}{16\pi^2} A_t \mu I(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2, \mu^2)$,
and $\epsilon_3 = \epsilon_0 + y_t^2 \epsilon_Y$.

\Rightarrow Strongly constraint.

Scanning the parameter space

Let's see if this idea works.

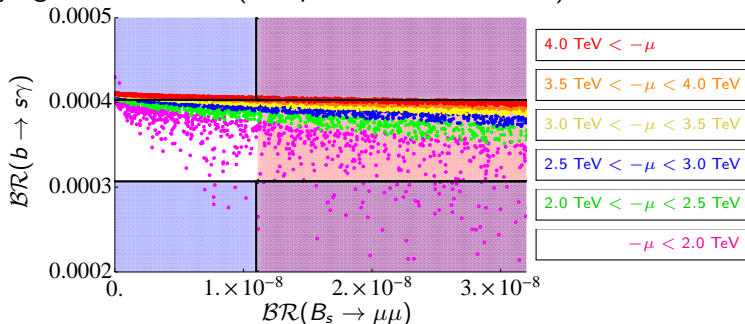
This is how we proceed

- 1 Set $\tan \beta = 50$ and choose random soft masses and trilinear terms $m_L = m_R, A_t = A_b, M_3 \in [0, 5] \text{ TeV}$.
- 2 Solve $\epsilon_0 = -3\%$ for $|\mu|$. (Demand $|\mu| \leq 5 \text{ TeV}$.)
Fix $m_{H^\pm} = 600 \text{ GeV}$ and $M_3 = -2M_2 = -6M_1$.
- 3 Calculate mass spectrum.
(Discard if masses are tachyonic or excluded, except by new LHC bounds.)
- 4 Calculate the other observables
- 5 Check.

Is there a region in parameter space that fulfills all this? Yes!

Results: $B \rightarrow \mu\mu$ vs. $b \rightarrow s\gamma$

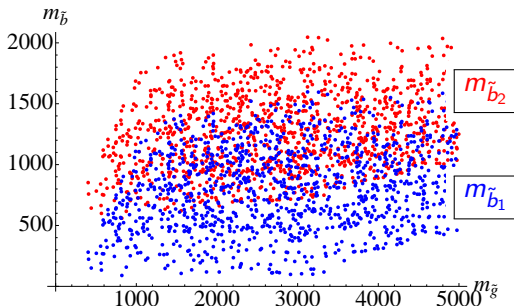
- Applying all constraints (except LHC mass bounds)



- These two observables restrict the parameters severely.
- BUT: Still a lot of points survive, favoring μ not too large.

Results: $m_{\tilde{b}}$ vs. M_3

- First two generations can be made heavy easily.
→ Look at **sbottoms only**, stops are similar (with less splitting).

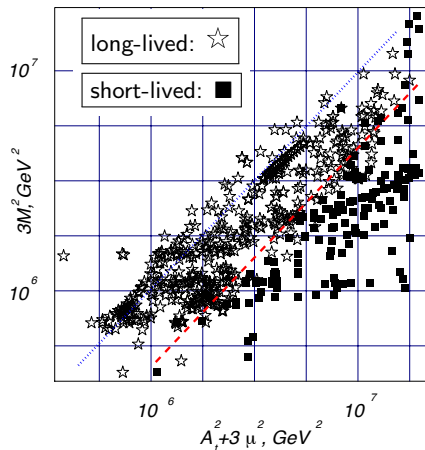


A lot of points survive bounds from direct LHC search

- Gluino is heavy: \sim few TeV.
- Lighter of the sbottoms (and also stops): few 100 GeV to \sim 1.5 TeV.

Vacuum stability: Can be a problem for large $|\mu|$

- Problem: SM-vacuum might not be a *global* minimum.



- SM-vacuum is a stable, global minimum if

Stability

$$A^2 + 3|\mu|^2 \lesssim 3(\tilde{m}_1^2 + \tilde{m}_2^2)$$

- [Kusenko, Langacker, Segre '96]: Vacuum must not be stable, as long as it is **metastable**:

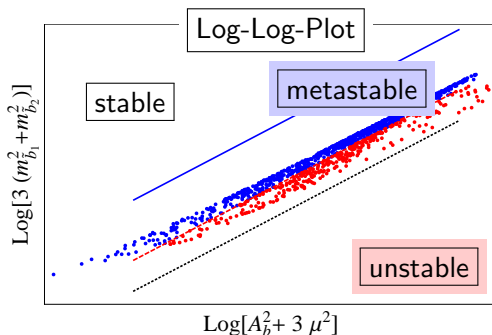
Metastability

$$A^2 + 3|\mu|^2 \lesssim 2.5 \times 3(\tilde{m}_1^2 + \tilde{m}_2^2)$$

Vacuum stability: Check our points

- Check if our parameters describe stable minima:

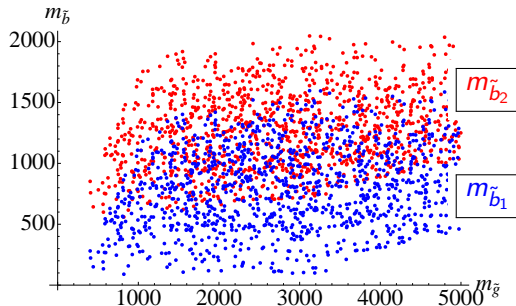
$$A_q^2 + 3\mu^2 \lesssim 2.5 \times 3(m_{\tilde{q}_1} + m_{\tilde{q}_2})$$



\Rightarrow No stable vacua, but a lot of metastable vacua.

Mass spectrum II: $m_{\tilde{b}}$ vs. M_3

- Look at sbottom spectrum for these metastable parameters



⇒ No big change from before:

- There are possible parameter points with:
~ few TeV gluino mass and ~ few 100 GeV - 1.5 TeV lighter sbottom mass.

Conclusion

- MSSM can give *positive* correction to $B \rightarrow \tau \nu$ amplitude, if
 - μ is negative and large (\sim few TeV)
 - $\tan \beta$ is large
- Also need:
 - $A_t > 0$ for $b \rightarrow s \gamma$.
 - $M_{1,2} < 0$ for $g_\mu - 2$.
- After constraints:
Get heavy gluino (\sim few TeV) and lighter sbottoms/stops (\sim TeV)
- Vacuum stability is a concern, but there are metastable parameter points.

MSSM with with large, negative μ & large $\tan \beta$ ($1 + \epsilon_0 \tan \beta < 0$)

Viable and interesting corner of parameter space.

Carlos' conclusion

"We are all going to die ..."

Carlos' conclusion

"We are all going to die ...
... but not anytime soon!"

Thanks for your attention